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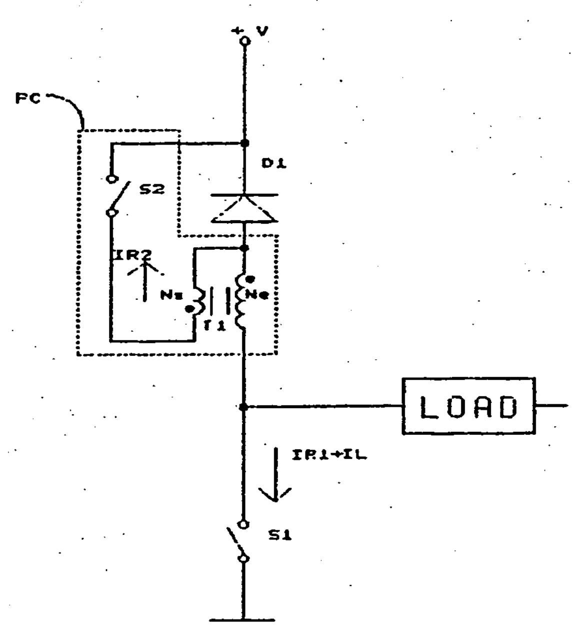
(54) Protective circuit for diode switching device.

(57) An electrical circuit supplying a load from a voltage source includes a switching device and a diode, and is to be protected from recovery current caused by polarity reversal of the diode during the operation of the switching device. The electrical circuit further includes a transformer having an excitation winding sensing the recovery current through the diode immediately after operation of the switching device, and a sink winding coupled to the excitation winding for inducing in the sink winding a reverse current corresponding to the current in the excitation winding. A unidirectional conducting device directs at least a portion of the reverse current from the sink winding back to the voltage source.

FIG 2
BASIC CONFIGURATION



EP 0 430 242 A2

PROTECTIVE CIRCUIT FOR DIODE SWITCHING DEVICE

The present invention relates to circuits for protecting systems which include diode switching devices against the effects of diode recovery currents which occur upon the reversal of the polarity of a diode.

One of the serious problems involved in electrical circuits including switching devices and diodes, such as power supplies, inverters, motor drivers, and the like, is the problem of recovery current resulting when the polarity of the diode is reversed. Thus, when a diode that was forwardly biassed is subjected to a reverse voltage, the diode behaves as a short circuit during the first few nanoseconds or microseconds until all the stored charge in the diode is recovered. This causes an extremely high magnitude of current, called recovery current, to flow through the diode and the switching device during this recovery period. This recovery current places a considerable stress on the diode and the switching device, and also wastes a considerable quantity of energy in the form of heat. This recovery current also causes energy accumulated in effective inductors and capacitors of the circuit to be radiated as electrical noise.

One known solution for this problem of diode recovery is to include an inductor in series with the electrical switch. While this solution protects the electrical switch, it does not solve the problem of wastage of energy. In addition, the inductor generates high-voltage spikes, and therefore it is common to include a zener diode to absorb the excess voltage, but this also does not solve the problem of wastage of energy. The common solution is to use an ultrafast acting diode, but such diodes are very expensive, if available at all, for particular applications producing a relatively high forward voltage drop.

The probelm is even more severe when using MOSFET's (metal oxide semi-conductor field effect transistor), particularly in bridge configurations. Thus, if the integral Drain/Source is allowed to conduct, the whole device is limited upon reapplying the dv/dt. In order to stay at a safe level of dv/dt, it is necessary to add a large serial inductance and large parallel capacitors. These components cause an additional waste of power. Another solution is to prevent conduction in the diode in the MOSFET by inserting a serial diode, to block backward conduction, and bypassing the MOSFET diode combination by an additional diode, parallel to the combination. However, these solutions are expensive and significantly increase the circuit losses.

An object of the present invention is to provide an electrical circuit of the foregoing type, i.e., including a switching device and a diode, with improved means for protecting the circuit from recovery current occurring when the polarity of the diode is reversed.

According to the present invention, there is provided an electrical circuit supplying a load from a voltage source, and including a switching device and a diode, which circuit is to be protected from recovery current caused by polarity reversal of the diode during the operation of the switching device, characterized in that the electrical circuit comprises: a transformer having an excitation winding sensing the recovery current through the diode immediately after operation of the switching device, and a sink winding coupled to the excitation winding for inducing in the sink winding a reverse current corresponding to the current in the excitation winding; and a unidirectional conducting device connected to direct at least a portion of the reverse current from the sink winding back to the voltage source.

The transformer may sense the recovery current directly, or indirectly, e.g., by reflection. Also, the unidirectional conducting device preferably has a voltage drop larger than that of the protected diode.

The invention may be implemented in many forms. For example, the unidirectional conducting device may be an electronic switch, a diode, or a plurality of diodes connected in series. The latter is particularly advantageous, since it is possible to manufacture small ultrafast diodes having high voltage drops which have no influence on the particular ciruit. Moreover, the current density in the plurality of diodes is extremely high, and therefore the charge which is accumulated during forward conduction is reduced.

The invention is also particularly advantageous when applied in MOSFET circuits, where the integral diodes normally exhibit a relatively high minority charge, and therefore cause long recovery time and high losses.

The turns ratio of the transformer determines the fraction of the current which flows away from the voltage source, and therefore which produces the power losses. Accordingly, the turns ratio should be kept as high as possible within practical limits. In this respect, a high turns ratio is difficult to achieve without increasing unwanted serial induction; diodes conducting during short periods tend to develop a forward voltage drop from several volts to several tenths of volts.

Further features and advantages of the invention will be apparent from the description below.

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

Fig. 1 is a circuit diagram illustrating a known basic switching diode circuit in which the diode polarity is reversed causing the problem of recovery current as described earlier; and

Figs. 2-17 illustrate various circuits in accordance with the present invention which may be used for solving or reducing this problem.

Reference is first made to Fig. 1 which illustrates the basic switching diode circuit. Thus, when a diode D1 that was forward biassed is subjected to a reverse voltage, the diode behaves as a short circuit for a short period of time (known as the recovery time) until all the stored charge is recovered. This generates a reverse current (IR) which, together with the load current (IL), is applied to the switching device (S1). Accordingly, this recovery current produces a momentary over-current and over-voltage which places considerable stress on the diode D1, may be destructive of the switch (S1), and also wastes a considerable amount of energy in the form of heat.

Figs. 2-17 illustrate different circuits which may be used according to the invention to recycle most of the recovered charge back to the voltage source. Thus, only a small fraction of the recovery current flows through the active switch, thereby solving or reducing the above problems.

Fig. 2 illustrates a basic configuration for solving or reducing the above problem. Thus, the protective circuit identified by block PC in Fig. 1 includes a transformer T_1 having an excitation winding N_E in series with the protected diode D_1 so as to sense the recovery current through the diode immediately after closing of the switching device S_1. Transformer T_1 also includes a sink winding N_S inductively coupled to the excitation winding N_E for inducing in the sink winding a reverse current correponding to the current in the excitation winding.

The protective circuit 1 illustrated in Fig. 2 further includes a unidirectional conductive device in the form of a switch S_2 in series with the sink winding N_S and connecting it across the protected diode D_1. Switch S_2, if not controlled, has a voltage drop larger than that of the protected diode D_1 and is therefore effective to direct at least a portion of the reverse current from the sink winding N_S back to the voltage source V.

It will thus be seen that the reverse current IR_1 which flows through the excitation winding N_E of transformer T_1 induces a much larger current IR_2 through the sink winding N_S, and switch S_2. Therefore, the inverse current IR_1 which flows from the voltage source v to switch S_1 is significantly smaller than the total diode recovery current. The part of the recovered charge which flows away from the voltage source V is thus significantly reduced, and so is the power loss.

Fig. 3 illustrates the same circuit as Fig. 2, and therefore the corresponding parts are identically numbered, except that an inductor L_1 is included in series with the excitation winding N_E and the switching device S_1 to further reduce the current stress on the switching device.

Fig. 4 illustrates a variation wherein the inductor L_1 is added in series with the sink winding T_S of the transformer T_1, instead of in series with the excitation winding N_E. Fig. 4 illustrates the further variation wherein the unidirectional conducting device is in the form of a pair of diodes D_2, D_3, providing the above-described advantages when using a diode pair for the unidirectional conducting device. In addition, the excitation winding N_E is connected to the switch S_1 in order not to interrupt the commutation action of diode D_1.

Fig. 5 illustrates a circuit wherein a cacpacitor C_1 is connected across the protected diode D_1 to limit the rate of voltage rise across the protected diode.

Fig. 6 illustrates an electrical circuit including a clamping diode D_4 connected across the excitation winding N_E and the switching device S_1 to protect the protected diode D_1 from voltage transients.

Fig. 7 illustrates an electrical circuit wherein a zener diode D_5 is connected across the switching device S_1, to limit the voltage rise on the switching device S_1.

Fig. 8 illustrates an electrical circuit wherein the transformer T_1 includes a second sink winding N_{2s} coupled to a second unidirectional conducting device D_7, which latter circuit further aids in recovering back to the voltage source energy stored in the transformer.

Fig. 9 illustrates an electrical circuit wherein the sink winding N_S of the transformer T_1 is connected to direct at least a portion of the recovery current back to the voltage source V via the excitation winding N_E of the transformer.

Fig. 10 illustrates an electrical circuit corresponding to that of Fig. 4 but embodied in a buck converter, wherein the switching device S_1 is a MOSFET, and the output of the protected diode is supplied to the load via a coil and capacitor.

Fig. 11 illustrates an electrical circuit similar to that of Fig. 10, but embodied in a boost converter type.

Fig. 12 illustrates an electrical circuit in which two diodes D_{1a}, D_{1b} are to be protected, each being protected by a sink winding N_{sa}, N_{sb} coupled to the excitation winding T_E in series with the switching device S_1.

Fig. 13 illustrates an electrical circuit including two MOSFET's, each protected by a protective circuit corresponding to that illustrated in Fig. 4. In

the circuit of Fig. 13, when one MOSFET acts as the switching device, the other acts as the diode to be protected.

Fig. 14 illustrates an electrical circuit including four MOSFET's arranged in a bridge configuration, including a single transformer and a single unidirectional conducting device. Thus, when two MOSFET's act as switching devices, the other two act as diodes to be protected. The single transformer T_1 includes a single excitation winding N_E and a single sink winding N_S effective, with unidirectional conducting device D_9 to protect all four MOSFET's.

Fig. 15 illustrates an electrical circuit wherein the sink winding N_S is connected to the excitation N_E at a point on the ladder remote from its connection to the protected diode D_1. The unidirectional device is shown as a diode D_8 but could be a plurality of diodes in series or an electronic switch.

Fig. 16 illustrates a circuit in which the transformer is split into two transformers T_{1a}, T_{1b}, in order to obtain higher turns ratios.

Fig. 17 illustrates an electrical circuit having two (or more) input circuits, each including an excitation coil T_E.

While the invention has been described with respect to a large number of preferred embodiments, it will be appreciated that these are shown merely for purposes of example, and that many variations, modifications and applications of the invention may be made.

where technical features mentioned in any claim are followed by reference signs, those reference signs have been included for the sole purpose of increasing the intelligibility of the claims and accordingly, such reference signs do not have any limiting effect on the scope of each element identified by way of example by such reference signs.

Claims

1. An electrical circuit supplying a load from a voltage source, and including a switching device and a diode, which circuit is to be protected from recovery current by polarity reversal of the diode during the operation of the switching device, characterized in that said electrical circuit comprises:

   a transformer having an excitation winding sensing the recovery current through the diode immediately after the operation of the switching device, and a sink winding coupled to said excitation winding for inducing in the sink winding a reverse current corresponding to the current in the excitation winding;

   and a unidirectional conducting device connected to direct at least a portion of the reverse current from the sink winding back to the voltage source.

2. The electrical circuit according to Claim 1, wherein said unidirectional conducting device has a voltage drop larger than that of the protected diode.

3. The electrical circuit according to either of Claims 1 or 2, wherein said unidirectional conducting device is an electronic switch.

4. The electrical circuit according to either Claims 1 or 2, wherein said unidirectional conducting device is a diode.

5. The electrical circuit according to any one of Claims 1-4, wherein said protected diode is in a semiconductor switching device.

6. The electrical circuit according to any one of Claims 1-5, further including a capacitor connected across said protected diode to limit the rate of voltage rise thereacross.

7. The electrical circuit according to any one of Claims 1-5, wherein said transformer includes a second sink winding coupled to a second unidirectional conducting device, the latter circuit further aiding in recovering back to the voltage source energy stored in the transformer.

8. The electrical circuit according to any one of Claims 1-5, wherein said transformer includes a second sink winding coupled to said excitation winding, and a second unidirectional conducting device connected to direct at least a portion of the reverse current from said second sink winding back to the voltage source.

9. The electrical circuit according to any one of Claims 1-5, where the sink winding is connected to direct at least a portion of the reverse current from the protected diode back to the voltage source via the excitation winding.

10. The electrical circuit according to any one of Claims 1-5, wherein the transformer is split into two transformer sections, one feeding the other, in order to obtain a higher turns ratio.

FIG 1

BASIC SWITCHING DIODE CIRCUIT

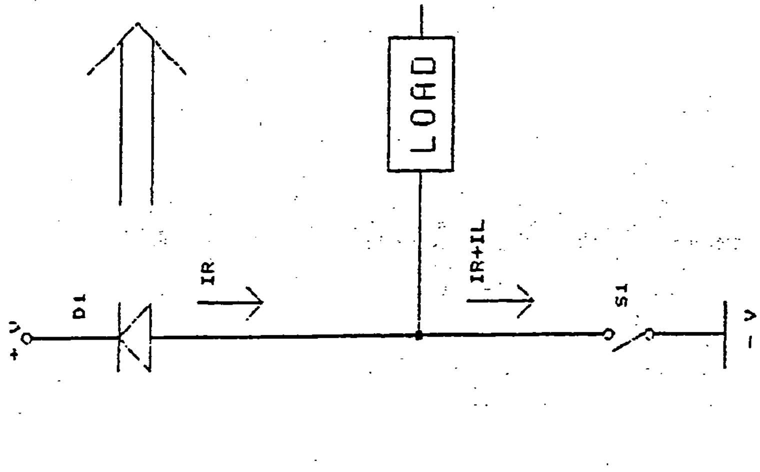


FIG 2

BASIC CONFIGURATION

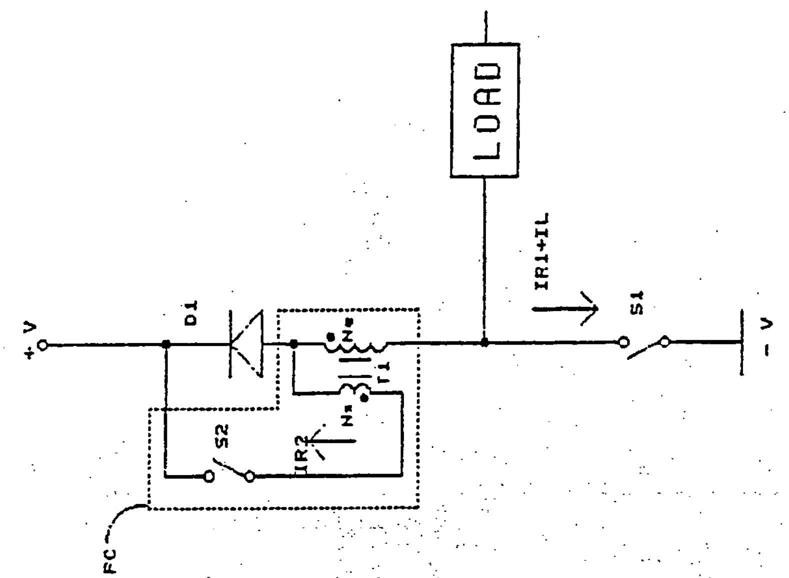


FIG3

INDUCTOR SERIAL TO MAIN CURRENT

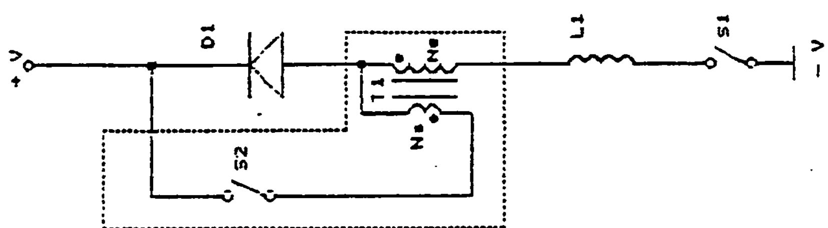


FIG4

PREFFERED EMBODIMENT

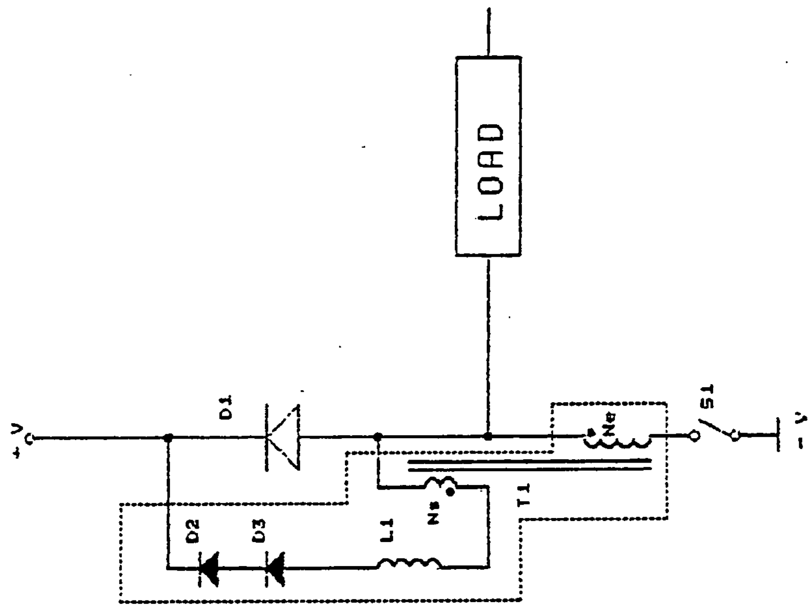


FIG5

DIODE PARASITIC CAPACITOR OR dv/dt CONTROL CAPACITOR

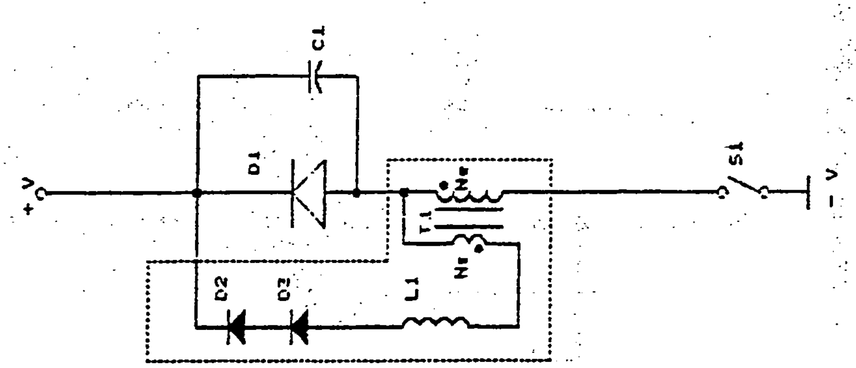


FIG 6

CLAMP DIODE ADDED

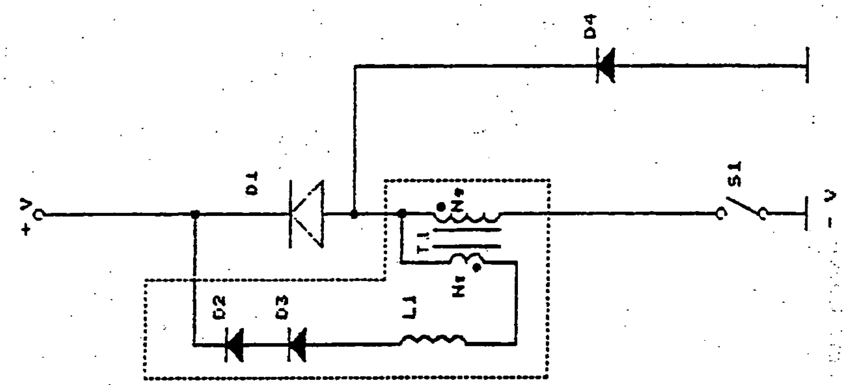


FIG7

SWITCH PROTECTION DIODE ADDED

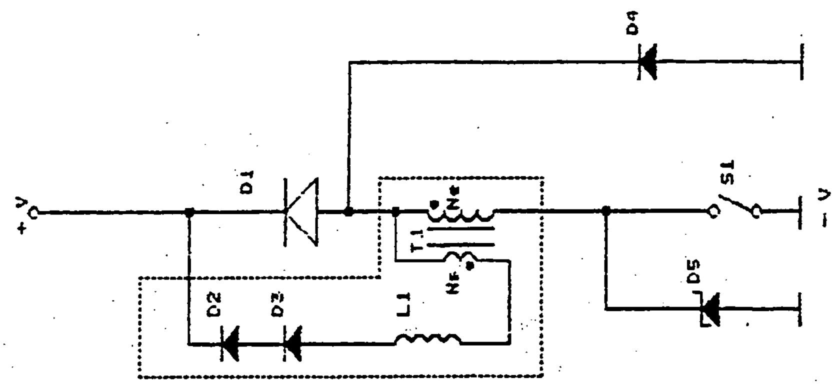


FIG9

SINGLE DIODE CONFIGURATION

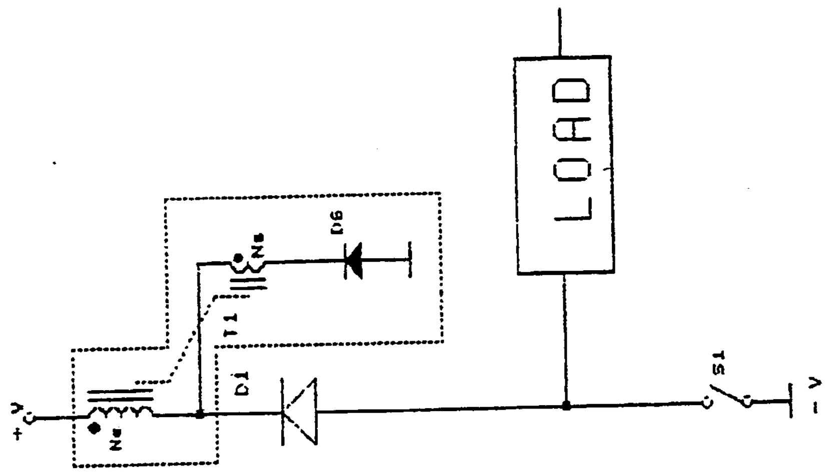
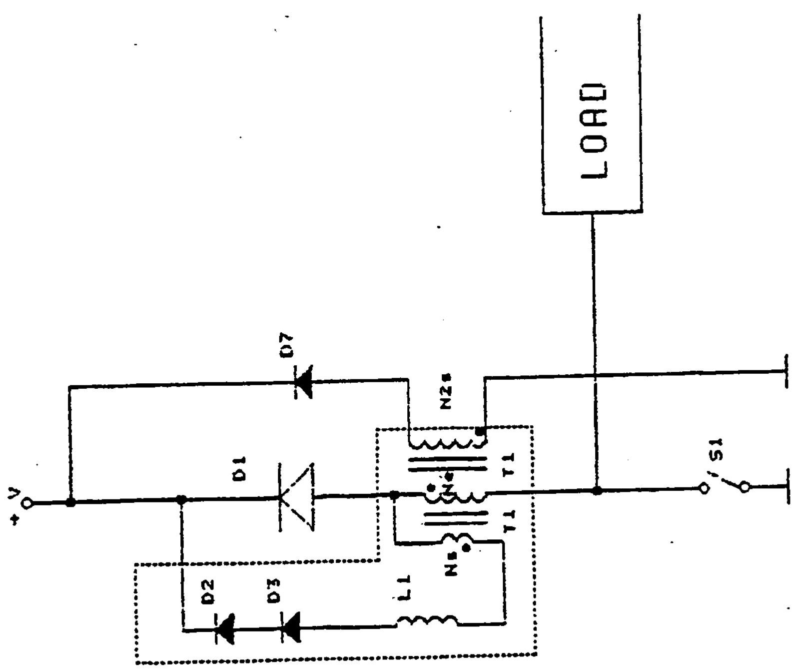
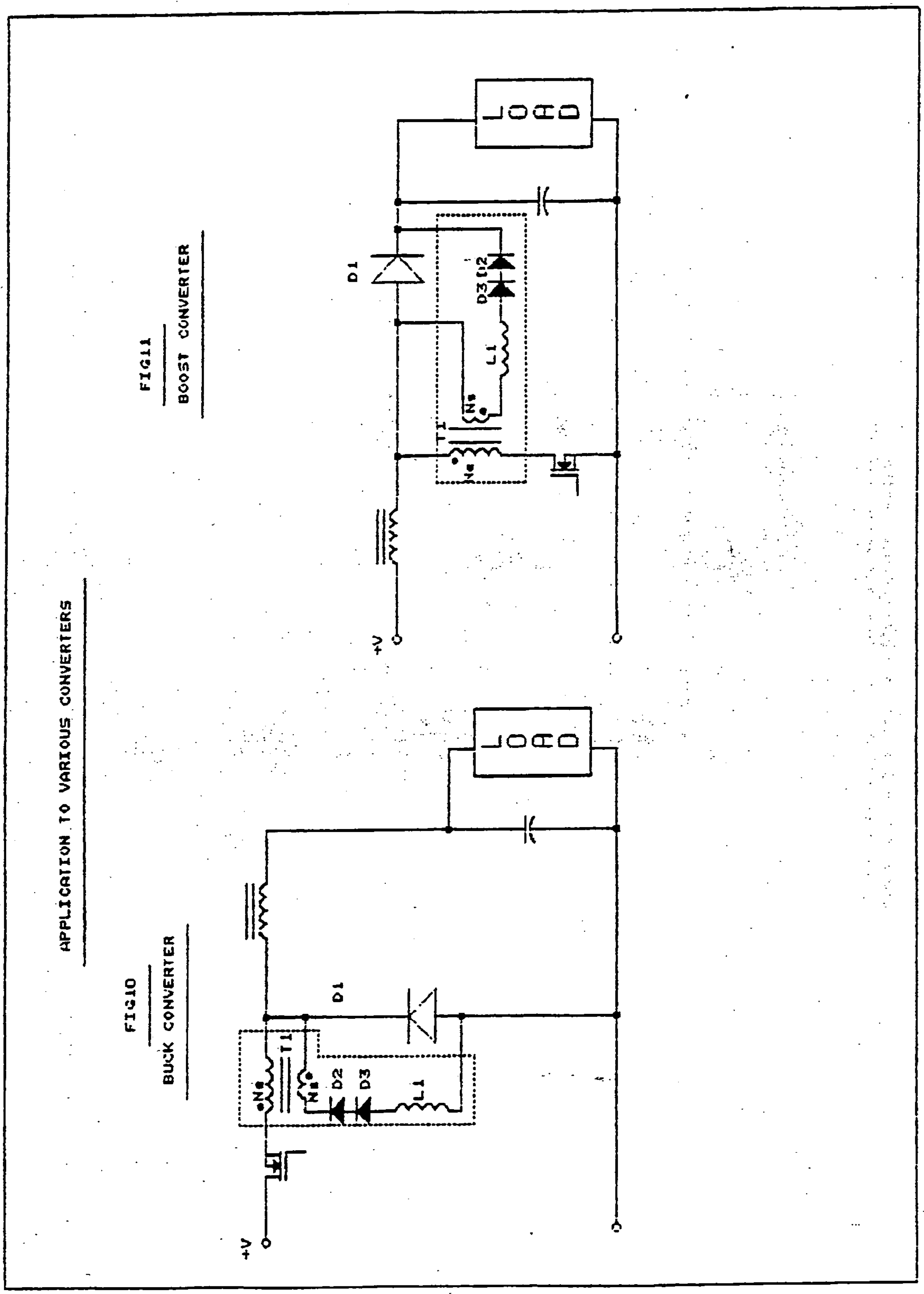


FIG8

WINDING ADDED TO RECICLE TRANSFORMER'S STORED ENERGY





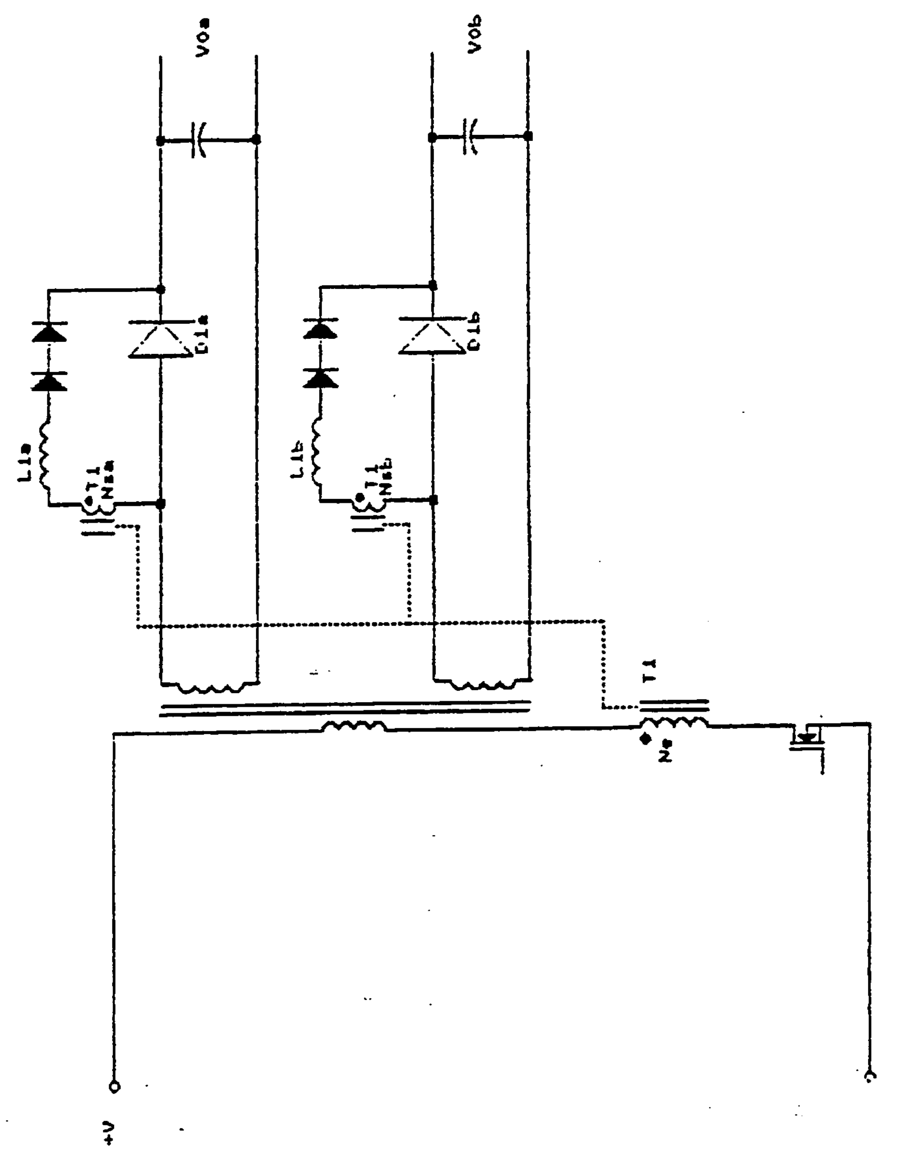
APPLICATION TO VARIOUS CONVERTERS

FIG10
BUCK CONVERTER

FIG11
BOOST CONVERTER

FIG12

COMMON EXITATION COIL & MULTIPLE SINK COILS



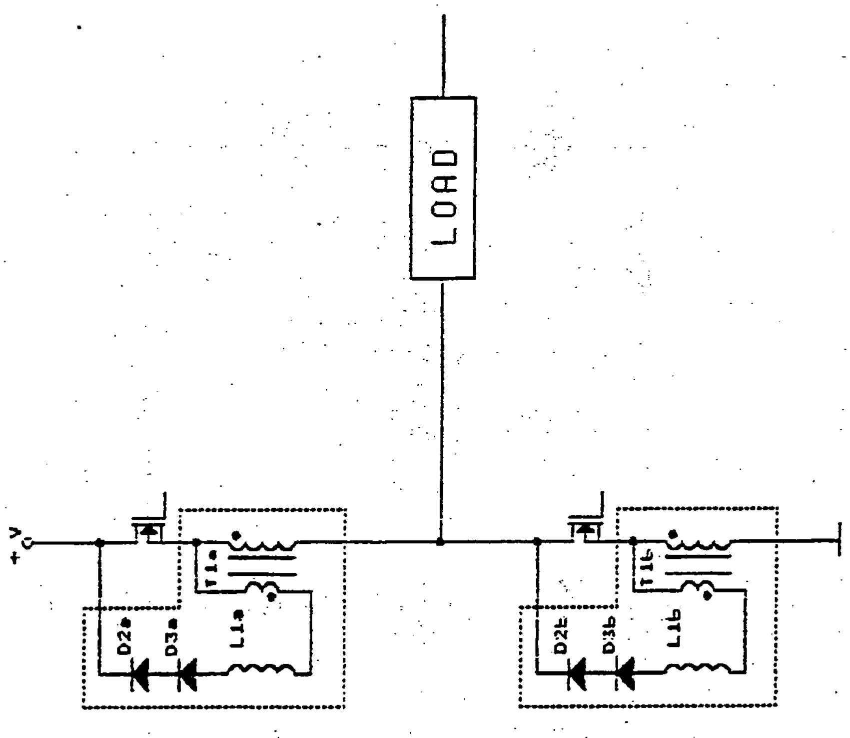
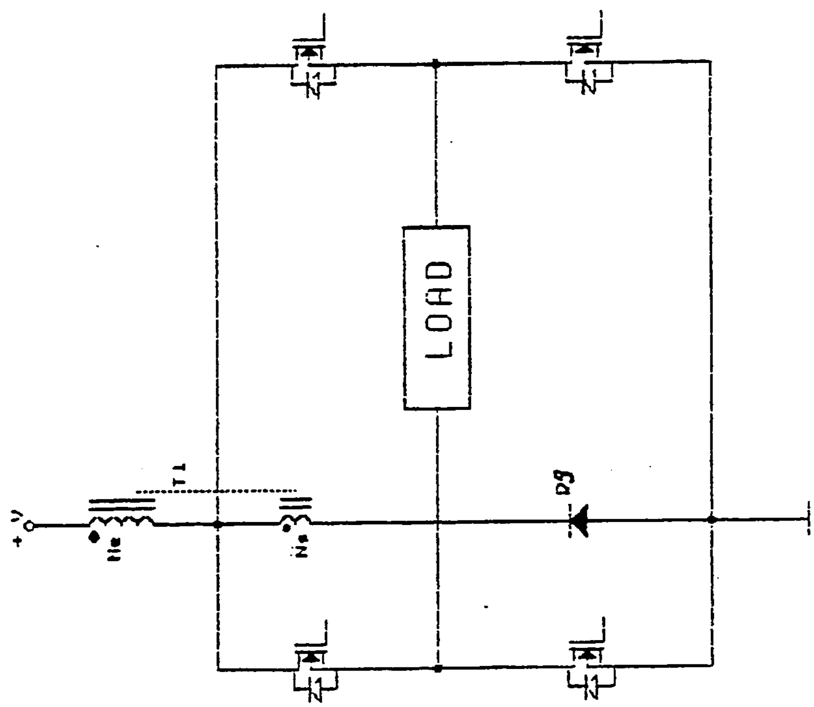


FIG13

PART OF BRIDGE CONFIGURATION

FIG.14

RECOVERY AID FOR POWER BRIDGE COMPRISES A SONGLE TRANSFORMER AND SINGLE DIODE



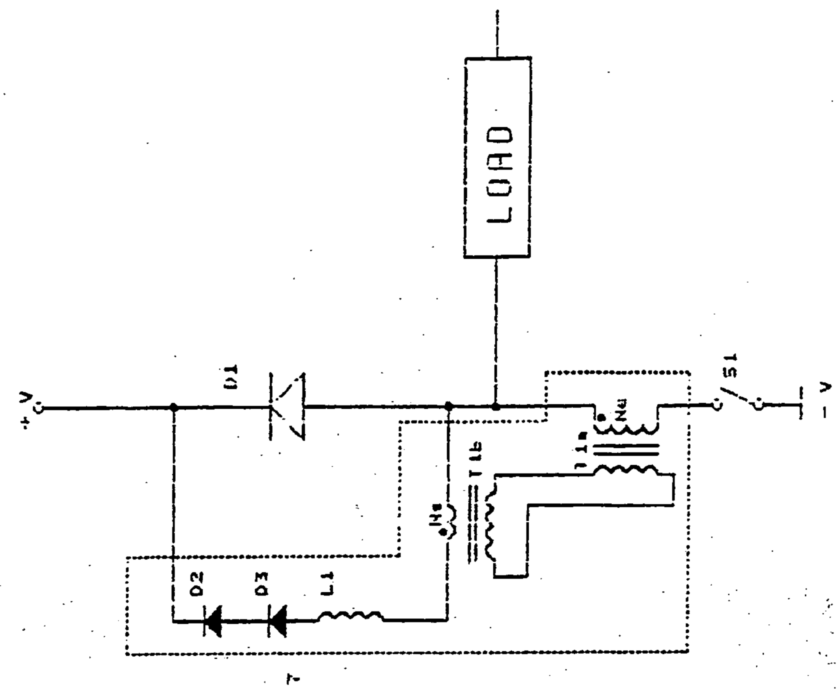


FIG16

TWO TRANSFORMERS EMBODIMENT

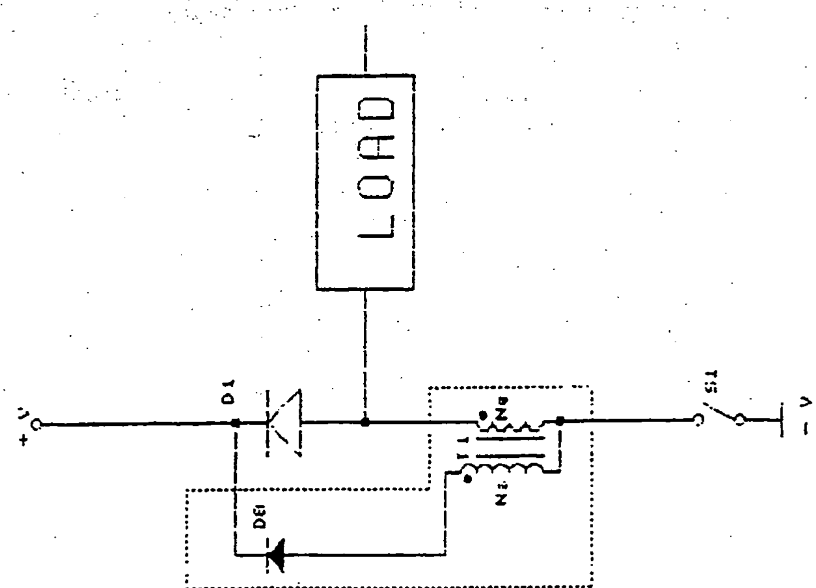


FIG15

SINGLE DIODE CONFIGURATION

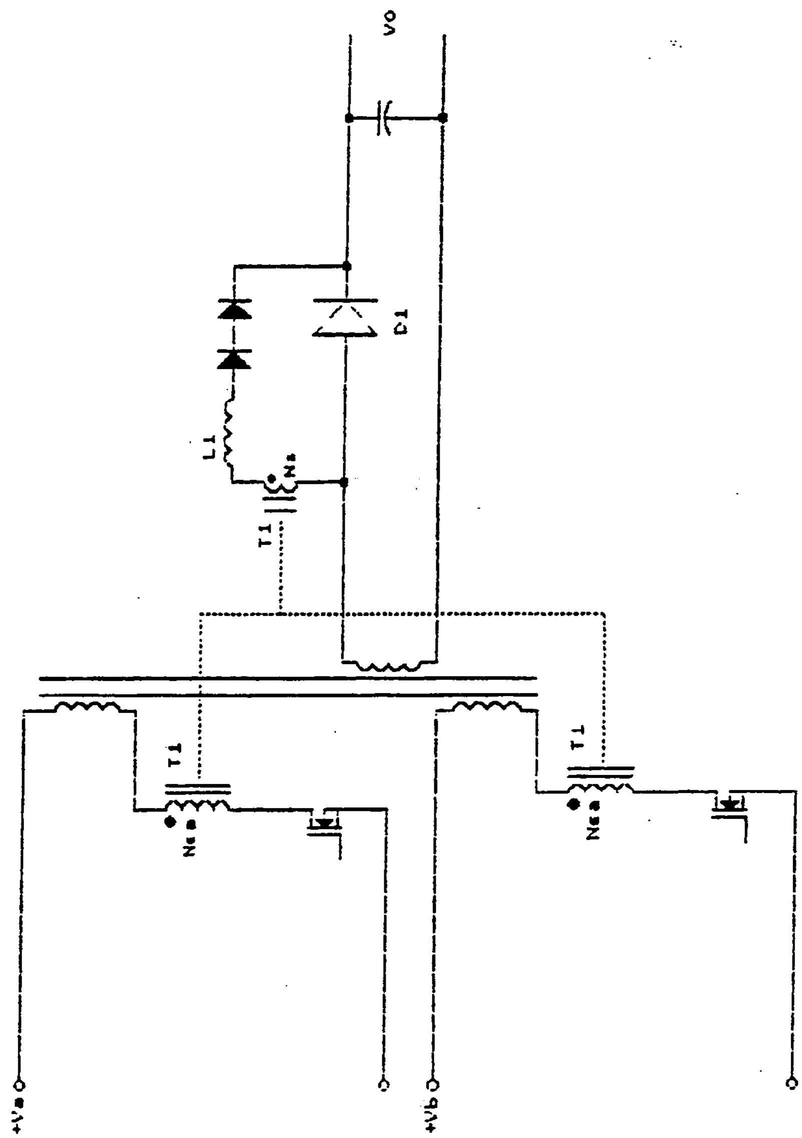


FIG17

TWO EXITATION COILS EXAMPLE

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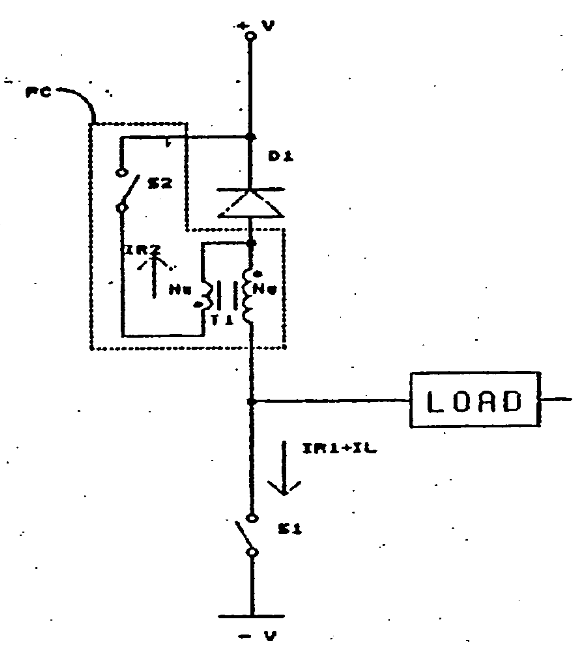
FIG 2
BASIC CONFIGURATION



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European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 90 12 2856

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	US-A-3 955 131 (PICCONE) * Abstract; column 5, line 61 - column 6, line 13; figures 1,2,6 * - - -	1,3,5	H 03 K 17/08 H 02 M 3/155
A	PATENT ABSTRACTS OF JAPAN, vol. 5, no. 23 (E-45)[695], 12th February 1981; & JP-A-55 150 776 (TOUKOU) 22-11-1980 * The whole document * - - - - -	1	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			H 03 K H 02 M

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	29 July 91	GENTILI L.

CATEGORY OF CITED DOCUMENTS

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E: earlier patent document, but published on, or after the filing date
D: document cited in the application
L: document cited for other reasons

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